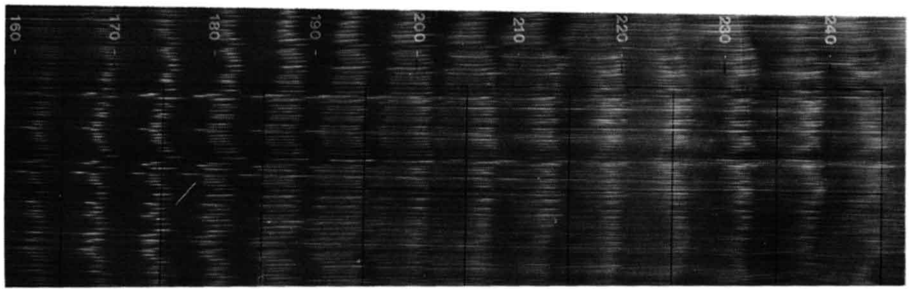

Figure 1(a)

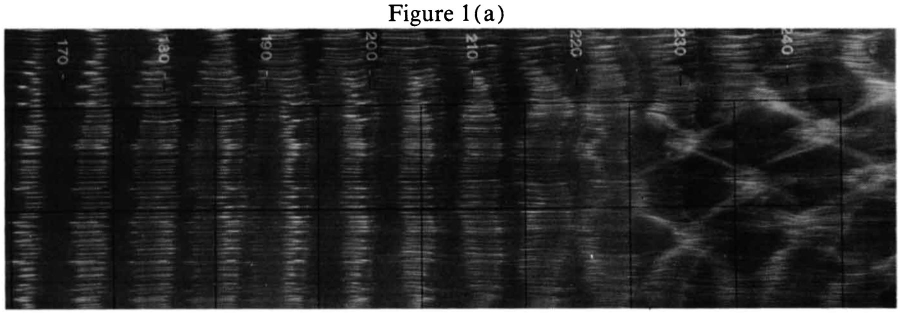

Figure 1(b)

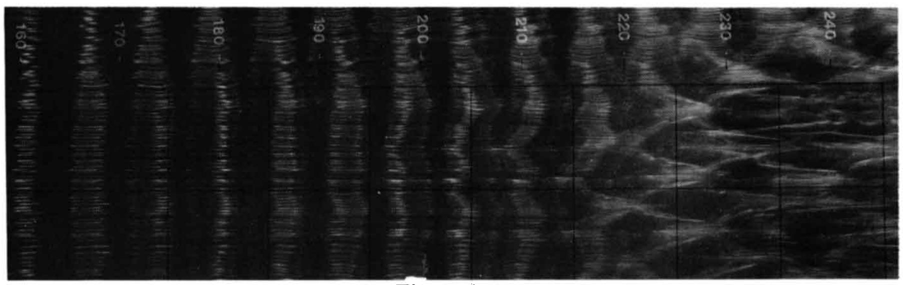

Figure 1(c)

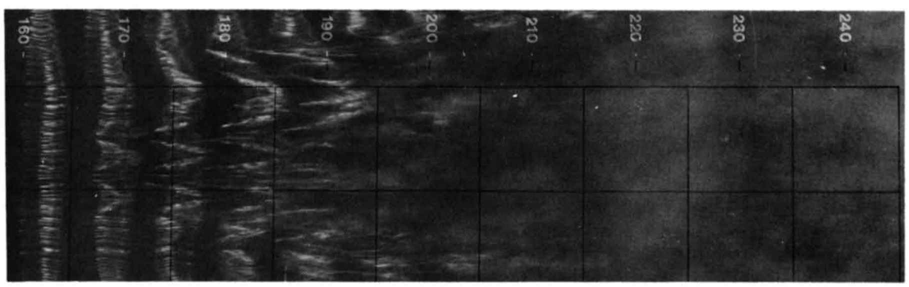

Figure 1(d)

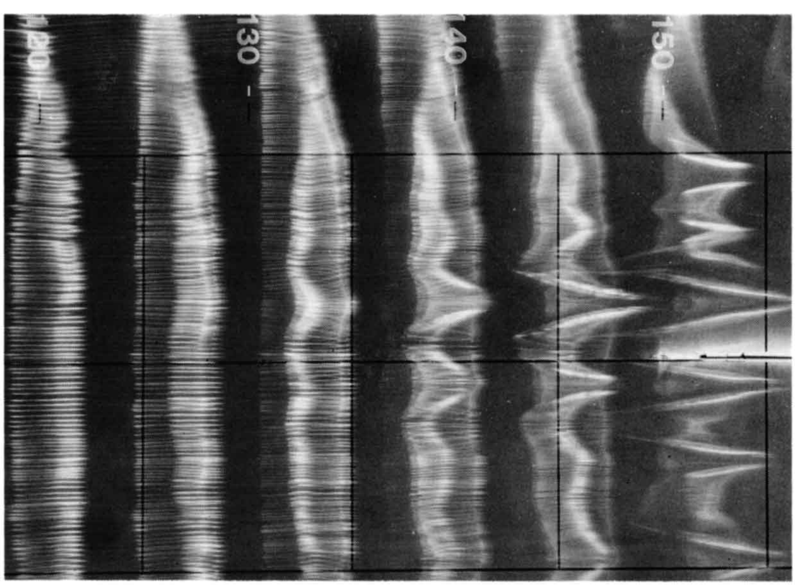

Figure 2

VISUALIZATION OF DIFFERENT TRANSITION MECHANISMS

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The sequence of photos in Figs. 1(a)–1(d) illustrates the different types of boundary-layer transitions that occur as a function of Tollmien–Schlichting (T–S) wave amplitude and fetch.[2] The presence of these different mechanisms was first revealed through flow visualization,[3] and subsequent hot-wire measurements[2–4] confirmed the details. The distance from the leading edge is shown in cm. Tollmien–Schlichting waves are introduced by means of a vibrating ribbon located at 48 cm (near branch I of the neutral stability curve) at a frequency of 39 Hz. The flow velocity is 6.6 m/sec. An IIT-type smoke wire is placed at $x = 138$ cm and $y = 0.1$ cm. Branch II of the neutral stability curve for dimensionless frequency $F = 83 \times 10^{-6}$ is $x = 170$ cm. The T–S wave amplitude is referenced to the branch II point.

Figure 1 shows (a) 2-D T–S waves where $u' = 0.2\%$, (b) staggered structure I where $u' = 0.3\%$, (c) staggered structure II where $u' = 0.4\%$, (d) an ordered peak–valley structure where $u' = 1\%$.

As the T–S wave amplitude is increased through Figs. 1(a)–1(d), the pattern changes from *regular* T–S waves to a *staggered* 3-D pattern with a *large* spanwise wavelength to a staggered pattern with a *small* spanwise wavelength to an *ordered* peak–valley pattern. The staggered peak–valley structure is a sufficient condition for the existence of subharmonics. Note that subharmonic breakdown occurs outside of the unstable region of the primary wave. This proved the value of the flow visualization. Reference 2 concludes that Fig. 1(b) is accounted for by the theory of Craik, while 1(c) is described by the theory of Herbert, and 1(d) is typical of the experiments of Klebanoff. Figure 2 is a closeup of the ordered peak–valley structure of the Klebanoff-type breakdown process.

This work was supported by the Air Force Office of Scientific Research under Contract Nos. 82-NA-0229 and 85-NA-077.